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Turbulent forced convection heat transfer of non-Newtonian nanofluids

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A B S T R A C T

Forced convection heat transfer of non-Newtonian nanofluids in a circular tube with constant wall temperature under turbulent flow conditions was investigated experimentally. Three types of nanofluids were prepared by dispersing homogeneously γ-Al_2O_3, TiO_2 and CuO nanoparticles into the base fluid. An aqueous solution of carboxymethyl cellulose (CMC) was used as the base fluid. Nanofluids as well as the base fluid show shear-thinning (pseudoplastic) rheological behavior. Results indicate that the convective heat transfer coefficient of nanofluids is higher than that of the base fluid. The enhancement of the convective heat transfer coefficient increases with an increase in the Peclet number and the nanoparticle concentration. The increase in the convective heat transfer coefficient of nanofluids is greater than the increase that would be observed considering strictly the increase in the effective thermal conductivity of nanofluids. Experimental data were compared to heat transfer coefficients predicted using available correlations for purely viscous non-Newtonian fluids. Results show poor agreement between experimental and predicted values. New correlation was proposed to predict successfully Nusselt numbers of non-Newtonian nanofluids as a function of Reynolds and Prandtl numbers.

1. Introduction

Energy conservation is undoubtedly the greatest preoccupation that engineers must face to render processes as economically viable as possible. More efficient heat transfer systems are vital to meet this challenge. Various heat transfer enhancement techniques have been proposed since the mid-1950s. However, the relatively low thermal conductivity of conventional heat transfer fluids is one of the main limitations in the improvement of heat transfer equipments. The thermal conductivity of most solids is much higher than conventional heat transfer fluids. Therefore, it is expected that the thermal conductivity of fluids containing dispersed solid particles would be significantly larger than that of the solid-free fluid. One heat transfer enhancement technique that was recently developed proposes the replacement of traditional heat transfer fluids with nanofluids.

Nanofluids are uniform and stable suspensions of metallic and/or non-metallic nanoparticles in a conventional heat transfer fluid such as water or ethylene glycol. Some review papers [1–3] include overviews of thermophysical properties of nanofluids and have discussed their potential applications in industry. More particularly, some researchers have investigated the convective heat transfer coefficient of nanofluids. They have used various kinds of nanoparticles such as Oxide nanoparticles [4–22], carbon nanotubes [23–25] and some other types of nanoparticles [26–29] in preparation of nanofluids. Water, ethylene glycol and transformer oil were often used as the base fluid. Both laminar [5–7,12–14,17–19,21,23–25,27] and turbulent [4,7–10,16,20,25,26,28–30] flow regimes were investigated. Gherasim et al. [15], Nguyen et al. [8], and Jwo et al. [22] have used a radial flow cooling system, a closed system designed for cooling of microprocessor or other electronic components, and a multi-channel heat exchanger for cooling of electronic chips respectively. All other investigators have studied convective heat transfer of nanofluids in circular tubes. Based on the results of these investigations the convective heat transfer of nanofluids improves remarkably over the base fluid and the enhancement of heat transfer coefficient increases by nanoparticle concentration. In general predicted values of heat transfer coefficient of nanofluids by conventional models for heat transfer of single-phase fluids are substantially lower than experimental values. Although it was expected that enhancement of thermal conductivity is the most important factor that improves the convective heat transfer coefficient of nanofluid, results of most investigations show that the improvement of heat transfer coefficient of nanofluids is higher than that solely attributed to the enhancement of thermal conductivity. Thus other factors are also influenced the convective heat transfer enhancement of nanofluids. Various parameters which affecting the heat transfer enhancement of nanofluids were described in some review articles [2,3,31–34].

Syam Sundar et al. [9] and Sharma et al. [30] have investigated convective heat transfer of nanofluids in plain tube and tube with

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